EPRI

INDUSTRY SEGMENT PROFILE

SIC 33991

Metal Powder Production

EPRI Center for Materials Production

000000000001000133

Table of Contents

List of Tables

List of Figures

Introduction

Powder metallurgy has been called a lost art. The art of molding and firing practical or decorative metallic objects is described in early recorded history as far back as 3000 BC. In succeeding centuries, however, sintering of metal was entirely forgotten. It was not until the end of the 18th century when various methods of making platinum powder were recorded. A brief summary of the major developments in powder metallurgy is given in Table 1 below.

Table 1. Major Historical Developments in Powder Metallurgy

Date	Description	Origin
3000 BC	"Sponge iron" for making tools	Egypt, Africa, India
AD 1200	Cementing platinum grains	South America (Incas)
1781	Fusible platinum-arsenic alloy	France, Germany
1790	Production of platinum-arsenic chemical vessels commercially	France
1822	Platinum powder formed into solid ingot	France
1826	High-temperature sintering of platinum powder compacts on a commercial basis	Russia
1829	Wollaston method of producing compact platinum from platinum sponge (basis of modern P/M technique)	England
1830	Sintering compacts of various metals	Europe
1859	Platinum fusion process	
1870	Patent for bearing materials made from metal powders (forerunner of self-lubricating bearings)	United States
1878-1900	Incandescent lamp filaments	United States
1915-1930	Cemented carbides	Germany
Early 1900s	Composite metals	United States
	Porous metals and metallic filters	United States
1920s	Self-lubricating bearings (used commercially)	United States
1940s	Iron powder technology	Central Europe
1950s and 1960s	P/M wrought and dispersion-strengthened products, including P/M forgings	United States
1970s	Hot isostatic pressing, P/M tool steels and superplastic superalloys	United States
1980s	Rapid solidification and powder injection molding technology	United States
1990s	Intermetallics, metal-matrix composites, spray forming, nanoscale powders and warm compaction	United States, England

In recent times, powder metallurgy has grown rapidly, both in the number of metal powders produced and in the quantity produced. Over the last ten years, double-digit increases in metal powder production were not uncommon.

Powder metallurgy covers a broad spectrum of manufacturing processes. Both the mechanical methods and the chemical/electrochemical methods for producing various metal powders are summarized in the manufacturing section of this report.

Atomization is the dominant method for producing metal and pre-alloyed powders from iron, steel, stainless steel, tool steel, superalloy, titanium alloy, aluminum and brass. Atomization accounts for nearly 70 percent by weight of all metal powders produced in North America. It is the dominant mode for powder production because high production rates favor economy of scale and because pre-alloyed powders can only be produced by atomization. Reduction of oxides and electrolysis are the other major methods of powder production.

Iron and steel account for 80 percent by weight of all metal powders produced annually. At slightly over nine percent of total annual powder production, the next most important metal powder is aluminum, followed by copper and its alloys (4.9%), and nickel (2%). All other powders combined account for only about 4 percent of annual metal powder production.

Thumbnail Sketch of Typical Production Plant

With the large variety of metal powders produced and the many methods that can be used, there is not a typical production plant in the industry. However, if we restrict powder production to that of iron or steel and the production method to atomization, the following is relatively typical:

Average No. of Employees	75
Annual Shipment Value	$20 Million
Annual Shipment Quantity	6,000 Tons of Metal Powder
Annual Electricity Consumption	7 Million kWh
Electricity Opportunities	Electric arc furnace additions to accommodate growing market demand, particularly from the automotive sector. Rotating electrode and plasma rotating electrode processes to produce high purity metal powders. Vacuum furnace processing to produce higher purity, higher cost metal powders.
Technology Trend	Improvements in gas atomization processing to meet tighter material specifications for higher strength parts applications. Production of high purity metal powders and nanoscale ultra fine powders.
Industry Issues	Price fluctuations in metal powder prices. Increased environmental issues as the industry continues to expand. More consolidations. Highest growth segment within the metals processing industry (about six percent per year).

Industry Characteristics

The industry is made up of companies manufacturing the following products:

- Iron and steel metal powders
- Stainless steel metal powders
- Other nickel based metal powders including superalloys
- Aluminum metal powders
- Copper metal powders
- Other Non-ferrous metal powders

Manufacturers of powder metal parts are not considered part of the powder metal production industry.

The 1997 total value of US metal powder shipments was $1.74 billion, and includes powder, paste and flakes (Figure 1).

- Iron and steel powder represented nearly 30% of shipments at $520 million (80% on tonnage basis).
- Aluminum and aluminum-base alloys comprised 11% of shipments at $195 million.
- Tungsten and tungsten base alloys made up 10% of shipments at $184 million.
- Copper and copper-base alloys represented nearly 9% of shipments at $150 million.

The largest metal powder producer in the US is Hoeganaes (Cinnaminson, NJ), with a 25% share of the iron and steel powder market and total sales of $130 million.

Pennsylvania accounted for nearly 20% of the metal powder production in the US, much of it located in St. Mary's, Eighty Four and Pittsburgh, PA. New Jersey and New York each occupy around 10% of the overall market.

The end use markets for metal powder were dominated by the automotive market, which according to the Metal Powder Industries Federation (MPIF) accounted for over 70% of all powder metal business in 1997 (Figure 2).

The second largest market for powder metal components was the recreational and hobby market, together with hand tools. This segment accounted for 10% of production in 1997 according to MPIF.

This industry was characterized by a high degree of consolidations, mergers, and acquisitions, particularly in 1998 and 1999.

- GKN plc (which owns GKN Sintered Metals) acquired Hoeganaes. Since GKN Sintered Metals is one of the largest powder metal (P/M) parts producers, the acquisition of the largest US ferrous powder producer created competitive concerns from other P/M parts producers.
- Carpenter Technology purchased a 51% interest in Parmaco AG in Switzerland.
- OMG acquired Dow Chemical's Division for producing fine tungsten carbide metal powders.
- US Bronze Powders acquired Pechiney Rhenalu in France and also purchased the remaining 50% interest in Makin Metal Powders.
- AcuPowder purchased the Niagara Falls, NY division of Pyron Corporation.

P/M processing operations are divided into powder production and powder consolidation. For the purposes of this report, the focus is on powder production.

Uses of Powder Metal

The major applications for P/M products continue to center around the automotive industry. About 50 pounds of P/M parts will be used in a typical U.S. model 2001 vehicle. Hot forged P/M connecting rods and camshafts are replacing those using other materials.

The 1998 metal injection molding (MIM) market is estimated at $100 million and continues to grow at 20 to 25% annually.

- Major MIM markets continue to be medical, automotive, and business machines/ electronics.

Hot isostatic pressing (HIP) applications are growing especially in high-speed steel, sputtering targets, and HIP clad composite markets.

- The North American P/M high-speed steel market is estimated at 6,500 tons annually.
- HIPed stainless steel products for oil field and land based power turbines are increasing, along with HIPed titanium for sporting goods applications.

Depending on their size, new commercial aircraft engines contain between 1500 and 4400 pounds of superalloy P/M hot extruded forgings per engine.

Other sectors of the P/M market continue to grow such as rapid prototyping, spray forming, metal matrix composites, metal foams and nanoscale powders.

- 60% of all tantalum powder is used in capacitors for electronics and telecommunications applications, including the high growth cell phone market.
- Stainless steel metal fibers are used in conductive plastics and heat resistant fabric for gas burners.
- Iron powder is used as a carrier for toner in electrostatic copying machines.
- About two million pounds of iron powder is used annually in iron-enriched cereals.

- Copper powder is used in anti-fouling paints for boat hulls and in metallic pigmented inks for printing and packaging.
- Aluminum powder is used in solid fuels for rockets and in aluminum paints.

The new North American Industrial Classification System (NAICS) data includes a category for users of powder metal (332117 - Powder Metallurgy Parts Manufacturing), the companies that powder metal producers supply. As shown in Table 2, companies within this classification comprise establishments primarily engaged in manufacturing powder metallurgy products by compacting them in a shaped die and sintering. Establishments in this industry generally make a wide range of parts on a job or order basis.

Table 2. Powder Metal Parts Producers

NAICS Number	Number of Establishments	Shipment Value ($1,000s)	Employees	Payroll ($1,000s)
332117	125	1,126,033	10,025	321,861

In 1997, the average wage for production workers manufacturing P/M parts was $15.43 per hour, approximately 5% lower than the average wage of all US manufacturing plant workers ($16.23 per hour).

P/M parts are used in a variety of end products including automobile engines and transmissions, auto brake and steering systems, lock hardware, garden tractors, snowmobiles, washing machines, power tools and hardware, sporting arms, copiers and postage meters, off-road equipment, hunting knives, hydraulic assemblies, x-ray shielding, oil and gas drilling wellhead components, fishing rods, and wrist watches. Canadian nickels are made from strip rolled from pure nickel powder.

National Statistics

Table 3. North American Metal Powder Shipments

Shipments, 1000 tons							
	1992	1993	1994	1995	1996	1997	1998
Iron & Steel	**246.3**	**287.55**	**337.85**	**347.17**	**350.6**	**389.4**	**410.6**
Stainless Steel	**NA**	**NA**	**NA**	**NA**	**NA**	**5.25**	**5.87**
CU & CU Base	**20**	**22.4**	**23.1**	**23.2**	**22.89**	**24.4**	**25.05**
AL	**29.7**	**29.5**	**43.7**	**37.0**	**34.2**	**44.4**	**48.05**
MO (E)	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**
W	**1.45**	**1.9**	**1.45**	**1.45**	**1.0 (E)**	**1.06**	**1.51**
W C	**4.5**	**5.2**	**6.2**	**10.8**	**11.2 (E)**	**6.9**	**7.23**
NI	**9.9**	**9.6**	**10.0**	**10.5**	**11.6 (E)**	**11.5**	**10.5**
SN	**0.95**	**1.1**	**1.25**	**1.0**	**1.0**	**1.04**	**1.08**
Total	**315.3**	**359.75**	**426.05**	**433.7**	**434.98**	**486.1**	**512.34**

E – Estimate NA – Not Available

Table 4. Trends for SIC 33991 - Metal Powders, Paste and Flakes

	1992	**1993**	**1994**	**1995**	**1996**
Industry Shipments ($Millions)	**1,107.2**	**1,221.5**	**1,562.4**	**1,872.5**	**1,932.7**
Employment * (1000s)	**12.7**	**13.4**	**14.2**	**15.8**	**12.3**
New Capital Expenditures ($Millions)*	**78.9**	**70.8**	**85.4**	**93.7**	**88.7**
Electricity Purchased* (Million kWh)	**769.9**	**783.0**	**871.4**	**964.2**	**1,013.2**
Full Production Capacity Utilization*	**69**	**86**	**81**	**81**	**79**

Industry shipment data is for SIC 33991 (Metal Powders, Paste and Flakes).
**Other data is for SIC 3399 (Primary Metal Products). SIC 33991 represents approximately 75% of SIC 3399.*

Significant North American Production Facilities

Table 5. North American Metal Powder Producers

Company	Specialty	Plant Location	Number of Employees
Hoeganaes	**Iron, steel and stainless steel**	**Cinnaminson, NJ Gallatin, TN**	**300 120**
Carpenter Technology	**Super alloy**	**Reading, PA**	**2,600***
Crucible Specialty Metals	**Tool steel, alloys, and stainless steel**	**Syracuse, NY Oakdale, PA**	**800* 70**
Quebec Metal Powders	**Iron and steel**	**Tracy, Quebec**	**350***
OMG Americas	**Stainless steel and nonferrous**	**Durham, NC Johnstown, PA Franklin, PA**	**150 110 90**
AcuPowder (and Pyron)	**Nonferrous**	**Union City, NJ Niagara Falls, NY Maryville, TN**	**80 185 45**
Alcoa	**Aluminum**	**Rockdale, TX**	**200**
Toyal America	**Aluminum**	**Joliet, IL**	**110**
Kobelco	**Iron and steel**	**Seymour, IN**	**105**
Domfer Metal Powders	**Iron and steel**	**Montreal, Quebec**	**100**
American Chemet	**Copper**	**East Helena, MT**	**90**
Ametek	**Stainless steel**	**Eighty Four, PA**	**80**
Special Metals Corp	**Superalloy**	**Princeton, KY**	**80**

**Also produce other products at these plant locations*

Source: Reference USA, Census Data and industry interviews

Figure 1. Value of 1997 US Metal Powder Shipments *(Source: US Census Bureau)*

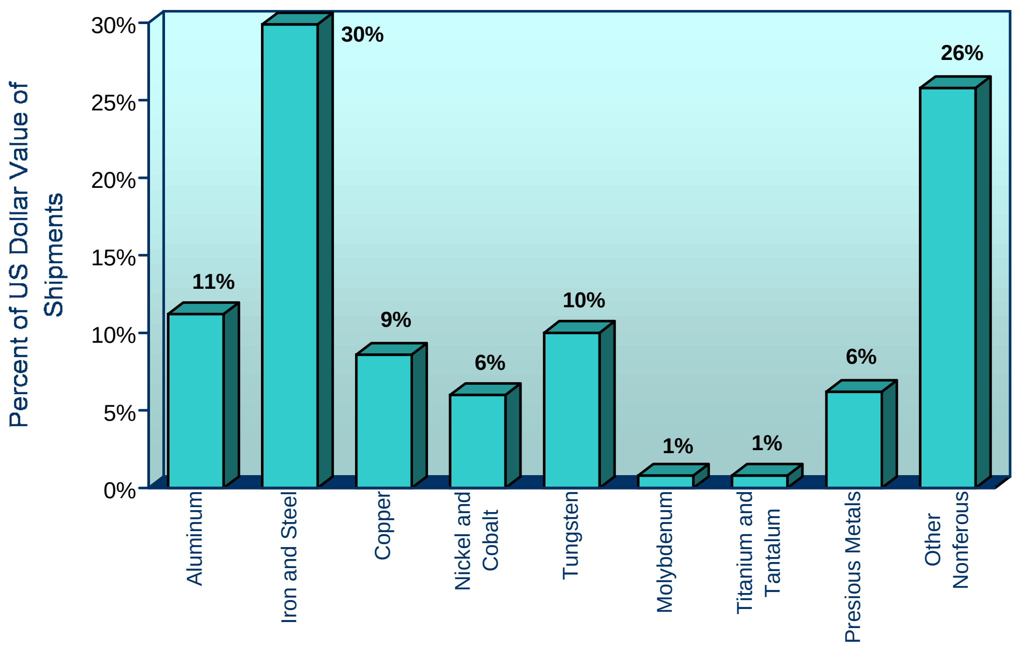
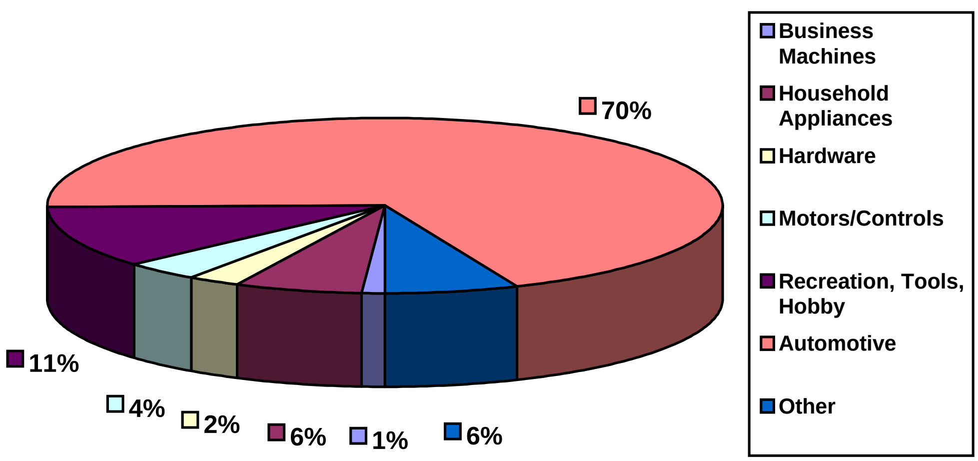


Figure 2. End-Use Applications for Metal Powder



Competitive Threats

Advances made by competitors selling castings, conventional forgings, stampings and plastic moldings that lower their cost relative to P/M, could slow the metal powder market growth.

The use of high-tech plastics and other composite parts can replace many P/M applications, particularly in the automotive industry.

- Issues such as federal fuel economy, emissions regulations, and gasoline prices continue to reduce vehicular weights, opening the door for lighter parts made of plastics and composites to replace metal parts although this may be offset somewhat by a move from P/M iron and steel parts to P/M parts made from lighter metals.

Improvements in the use of carbide, sintered diamond, sintered cubic boron nitride, ceramics, cements, and surface hardening techniques could adversely affect the market growth of P/M high speed steels and tool steels for cutting.

Hybrid propulsion systems using small reciprocating engines or fuel cells in combination with electric drive motors may reduce the market potential for P/M parts in engines.

The substitution of continuously variable transmissions (CVTs) for conventional stepped transmissions may reduce the market potential for P/M parts in transmissions unless the CV transmissions are redesigned for P/M parts.

The use of diesel engines in place of gasoline engines in trucks may result in higher strength specifications that P/M suppliers may not be able to cost effectively meet or may accelerate the use of P/M forged parts.

P/M companies have shown a hesitancy to embrace the Internet as a part of their business culture and this may slow their ability to compete against substitute products.

The conversion cost from the base metal to a metal powder is a critical issue in the ability of metal powder producers to compete with conventional casting and forging technologies. However, P/M parts have a competitive advantage in that they can be made to net or near net shape and thus require less machining.

- Conversion costs vary depending on the type of metal and the process used.
  - Conversion costs for iron powders using water atomization can be as low as $0.20/lb.
  - Conversion costs for nickel based superalloys using gas atomization will be in the range of $6 to $15 above base metal prices.
  - Conversion costs for titanium based alloys using gas atomization or other vacuum processing may be as high as $10 to $20 above base metal prices.

Investment Issues

Companies within this $1.7 billion industry typically have a large proportion of their assets invested in metal melting and atomization equipment. This investment is not considered out of line when compared on a percentage basis to the significant outlays required in the broader primary metals industry.

- New capital expenditures for SIC 3399 averaged 3.5% of industry shipments for 1992 to 1996.
  - In 1995 and 1996, new capital expenditures averaged 4% of industry shipments for the primary metals industry (SIC 33).
  - In 1995 and 1996, new capital expenditures averaged 3.4% of industry shipments for the fabricated metal products industry (SIC 34).
- Hoeganaes recently invested $18 million to double its iron and steel powder manufacturing capacity to 350,000 tons, adding approximately $120 million to its revenue stream. Using a depreciation schedule based on 5 years, this capital expenditure amounts to just 3% of expected shipments.

National Trends

The North American P/M industry has enjoyed steady growth through much of the 1990's with metal powder shipments reaching 511,185 short tons in 1998. This figure represents a 73% increase since 1989, greatly exceeding the 11% increase for US steel production over the same period of time.

- The US P/M industry is the highest growth segment of the metal production industry.
- The fastest growing markets within P/M include iron and steel, stainless steel, aluminum, copper, and tool steel powders.
- The auto market continues to dominate the P/M parts industry.
  - Nearly 70% of all P/M parts produced are consumed by the auto industry.
  - The typical family vehicle contained over 35 pounds (15.9kg) of P/M parts for the 1999 model year, up from 24 pounds (10.9kg) in 1990, which represents an increase of almost 46%.
  - Some SUV models contain as much as 60 pounds (27.2kg) of P/M parts.

Iron and steel powder shipments represent 80% of all North American powder shipments by weight and 30% of all North American powder shipments by value.

- P/M iron and steel parts represent 92% of all iron powder shipments.
  - Other end uses include additives for pigments, composites and more obscure uses such as iron powder for cereals. (Nearly 2 million pounds of iron powder are consumed each year in cereal).

1998 North American P/M parts sales were approximately $2 billion, compared to worldwide P/M parts sales of $5 billion.

- The US is the single largest market for P/M parts.

From 1992 to 1996, use of P/M parts grew at twice the rate of the previous 15 years.

Individual metal powder markets grew approximately 5% in 1998 compared to 1997.

- Iron and steel powder shipments increased 4.7% to 410,553 tons, the eighth consecutive year of increases for iron and steel powder. The growth rate is projected at 4% to 6% through 2005.
  - The strength of the US auto industry drives this market. By contrast, the Japanese iron and steel powder shipments declined 5.6% in 1998 to 170,968 tons due to their economic slowdown particularly in the auto industry.
  - Powder forging market share represents 9% of total iron and steel powder shipments.

- Copper and copper-based powders grew 2.5% in 1998 to 25, 051 short tons.
- Stainless steel powder shipments reached a record 5,875 tons in 1998, an increase of 12% over 1997.
  - End uses for the stainless steel powders include exhaust system parts, ABS system parts, lock hardware, and appliances.
- Aluminum powder was very strong in 1998 reaching 48,046 tons, an increase of more than 8% over 1997.
  - A resurgence of interest in aluminum P/M by design engineers will result in dramatic growth in auto applications such as cam cap bearings, mirror brackets, shock absorber parts, gerotors, pumps, and connecting rods.

Hoeganaes will be expanding its production capacity at Gallatin, TN to 350,000 tons of powder annually. The $18 million capacity addition will begin operating in early 2001.

- Targeted applications include connecting rods, helical pinion gears, carriers and bearing caps for the automotive industry

Hoganas (a Swedish company not to be confused with Hoeganaes) has opened its North American headquarters in Lehigh Valley, PA and will be constructing a 100,000 tons per year powder production facility in Hollsopple, PA near Johnstown.

- Production capacity will be geared to iron and steel powder, with the majority directed toward automotive applications.

Other auto applications include P/M parts in engines and transmissions for the year 2002 models, such as hot forged P/M connecting rods and camshafts. The growth of P/M parts in automobiles is the result of increased use in engines, transmissions, brakes, airbags and other complex parts.

- Engines consume more powder metals than any other automotive subassembly.
  - GM's next generation of V-6 are expected to consume more than 20 pounds in each engine, for a total of 30 million pounds of iron, steel and other powders annually beginning in 2002. Potential suppliers for the metal powder to GM include Domfer (Montreal), Hoeganaes (NJ), Kobelco (IN), and Quebec Metal Powders (Quebec).
- Planetary carrier assemblies and high torque gears will be additional markets for the P/M higher strength applications.
- Ford is aiming for the use of 50 pounds of P/M parts in vehicles by 2000.

Market Structure

The metal powder producing market consists of approximately 85 establishments in North America.

- The dominant company continues to be Hoeganaes, which produces over 25% of the iron and steel powder, but occupies only a 10% market share based on sales volume due to the lower cost of these powders ($0.35 to $0.40/lb). Estimated 1998 Hoeganaes sales were $130 million.
  - GKN's purchase of Hoeganaes in January, 1999 created one company controlling the dominant market share in P/M parts (GKN Sinter Metals with a 15% market share) and the dominant market share in metal powders.
- Other specialty powder manufacturers (including Carpenter, Crucible, Ametek, AcuPowder, Special Metals Corporation, OMG Americas, Alcoa, US Bronze, and American Chemet) produce lower volume powders that are more expensive.

Companies specialize according to the types of metal powder produced. There is considerable variation of the dominant manufacturers across the different metal powder segments. Key players in each of the specific industry groups are as follows:

- Iron and steel powder
  - Hoeganaes (300 employees at Cinnaminson, NJ and 120 at Gallatin, TN)
  - Quebec Metal Powders QMP (350 employees at Tracy, Quebec)
  - Pyron (185 employees at Niagara Falls, NY and 45 at Maryville, TN)
  - Kobelco (105 employees at Seymour, IN)
  - Domfer Metal Powders (Montreal, Quebec)
- Stainless steel powder
  - Ametek Specialty Metal Products (80 employees at Eighty Four, PA)
  - Hoeganaes (Cinnaminson, NJ and Gallatin, TN)
  - OMG Americas (350 employees in Research Triangle, NC area)
- Superalloy and other nickel based powder
  - Carpenter (2, 600 employees at Reading, PA) (Plant produces conventional stainless steel products also.)
  - Crucible (800 employees at Syracuse, NY and 70 at Oakdale, PA) (Plant produces conventional stainless steel products also.)
  - Special Metals Corporation SMC (80 employees at Princeton, KY)

  - Homogenous Metals (Herkimer, NY)
- Tool steel powder
  - Crucible (Syracuse, NY)
  - Carpenter (Reading, PA)
- Other ferrous powder
  - F.W. Winter (30 employees at Camden, NJ)
- Aluminum powder
  - Alcoa (200 employees at Rockdale, TX)
  - Toyal America (110 employees at Joliet, IL)
  - Ampal (30 employees at Palmerton, PA)
  - Valimet (75 employees at Stockton, CA)
  - Non Ferrum of America (Louisville, KY)
- Other Non-ferrous powder
  - OMG Americas (Research Triangle, NC)
  - AcuPowder International (80 employees at Union, NJ, also purchased Pyron)
  - US Bronze Powders (100 employees at Flemington, NJ and 25 at Maryville, TN)
  - American Chemet (90 employees at Helena, MT and 10 at Deerfield,IL)

This production information is also summarized in Table 5.

Summary of Industry Issues

Segments of the metal powder production industry are experiencing high growth rates, which have been driven primarily by the success of P/M parts in the automotive industry.

- P/M is the highest growth segment of the metal processing industry
- From 1992 to 1996, demand for P/M parts grew at twice the rate of the previous 15 years.
  - The highest growth metal powders are stainless steel compositions, projected to grow at 12% annually. Increased use in automotive exhaust systems is the primary driver.
  - The highest growth end use process is the metal injection mold (MIM) process, projected to grow 20% to 25% annually. Principal applications for MIM have been in medical and electronics, but will increasingly be found in the production of automotive parts.

Industry consolidations, especially the 1999 purchase of Hoeganaes by GKN, have had a significant impact on the market structure of the industry. Users of P/M parts are hopeful that this dominant, vertically integrated company will use its position to put downward pressure on prices and expand the overall metal powder market.

Most P/M parts weigh less than 5 pounds, although parts weighing as much as 35 pounds can be fabricated in conventional P/M equipment.

P/M typically uses more than 97% of the starting raw material in the finished part, significantly higher than material usage in conventional metal processing. Advantages of the P/M process include:

- Eliminates or minimizes machining
- Eliminates or minimizes scrap losses
- Maintains close dimensional tolerances
- Permits a wide variety of alloy systems
- Produces good surface finishes
- Provides materials which may be heat-treated for increased strength or increased wear resistance
- Provides controlled porosity for self-lubrication or filtration
- Facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metalworking processes
- Parts can be made to net or near net shape
- Hot powder forging can make fully dense parts
- Suited to moderate -to high volume components production requirements

- Rapid solidification allows extension of solubility limits, production of novel phases, and more refined microstructures than conventional metallurgical techniques
- Permits the production of metal-matrix composites
- Permits the production of nanostructured materials

Energy Consumption Patterns

Production of metal powders is generally less energy intensive than that of conventional metal products, such as sheet or bar, because hot and cold rolling is not involved in the production of powder. The energy for powder production varies according to the type of metal and the process used (Table 6).

Powder processing techniques for producing parts require 25% less energy overall than conventional precision forged steel products when scrap loss is considered.

- Deformation requires a considerable portion of the total energy expended in wrought processing.
- In powder processing, 50% of the total energy requirement is attributable to powder manufacture and heat treatment. The remaining operations have less significant energy needs.

Table 6. Energy Consumption in Fabricating Precision Forged Products

	Energy (MBtu/ton)					
	Wrought processing			Powder processing		
Operations	Steel	Aluminum	Copper	Steel	Aluminum	Copper
Casting*	**8.4**	**152**	**41**			
Powder Production				**15.1**	**153**	**46**
Primary Deformation	**18.4**	**1**	**1**			
Powder Compaction				**0.4**	**1**	**1**
Sintering or Heat Treatment	**3.0**			**13.0**	**8**	**10**
Supplemental Deformation				**0.4**	**1**	**1**
Finishing	**2.5**	**2**	**3**	**0.5**	**1**	**1**
Scrap Loss (not defined)	**6.7**					
Total Energy Required	39.0	155	45	29.4	164	59

**Includes power requirements for melting and refining*

Source: ASM International

Aluminum and copper wrought products that have been cold forged require no heat treatment after forging. Depending on the specific process steps required, powder processing may have little energy advantage, or actually be more energy intensive than wrought copper and aluminum products.

The energy for powder production varies according to the type of metal and the process used (Table 7).

Table 7. Energy Consumption for the Production of Metal Powders

	Energy (MBtu/ton)			
Operations	Powder Production	Grinding, Drying, Cleaning	Heat Treatment	Total
Iron				
Atomization	**8.4**	**1.7**	**5.0**	**15.1**
Reduction	**13.0**	**1.9**	**5.0**	**19.9**
Electrodeposition	**30.00**	**1.8**	**5.0**	**36.8**
Direct Recycle		**1.6**	**5.0**	**6.6**
Aluminum				
Atomization	**22.0**	**1.7**		**23.7**
Copper				
Atomization	**11.0**	**1.7**	**3.5**	**16.2**

*Includes power requirements for melting and refining

Source: ASM International

Typical Electricity Requirements

In 1996, the $2.5 billion primary metal products, nec (SIC 3399) used 1.0 billion kWh of electricity at a cost of $60 million dollars. Metal powders, paste and flakes (SIC 33991) represents 76% of this total.

- Electricity accounts for 70% of total purchased energy costs.
- Total energy costs are about 3% of shipment revenues.
  - This figure is less than the 4.6% reported for the primary metals industry (SIC 33), but higher than the 1.5% reported for fabricated metal products (SIC 34)

As shown in Table 8, metal powder producers need twice as many kWh as Blast Furnaces and Steel Mills (SIC 3312) to produce one dollar of value added product. Metal powder producers need 3 to 4 times the electricity compared to Sheet Metalwork (SIC 3444) and Motor Vehicle Parts (SIC 3714) producers to produce one dollar of value added product.

Table 8. Intensity of Electricity Consumption and Capital Investment

Industry SIC Code	1996 Value Added ($, Million)	Electricity Purchased (kWh, Million)	KWh/ VA	Mach./Equip. Assets ($, Million)	Mach. & Eq. Assets/ $ VA
3399	**$1,078.3**	**1,013.2**	**0.94**	**$830.7**	**0.77**
3312	**$22,111.9**	**144,305.3**	**0.48**	**$34,401.6**	**1.55**
3444	**$7,512.7**	**1,471.6**	**0.20**	**$2,424.9**	**0.42**
3714	**$44,209.9**	**15,559.4**	**0.35**	**$26,709.4**	**0.86**

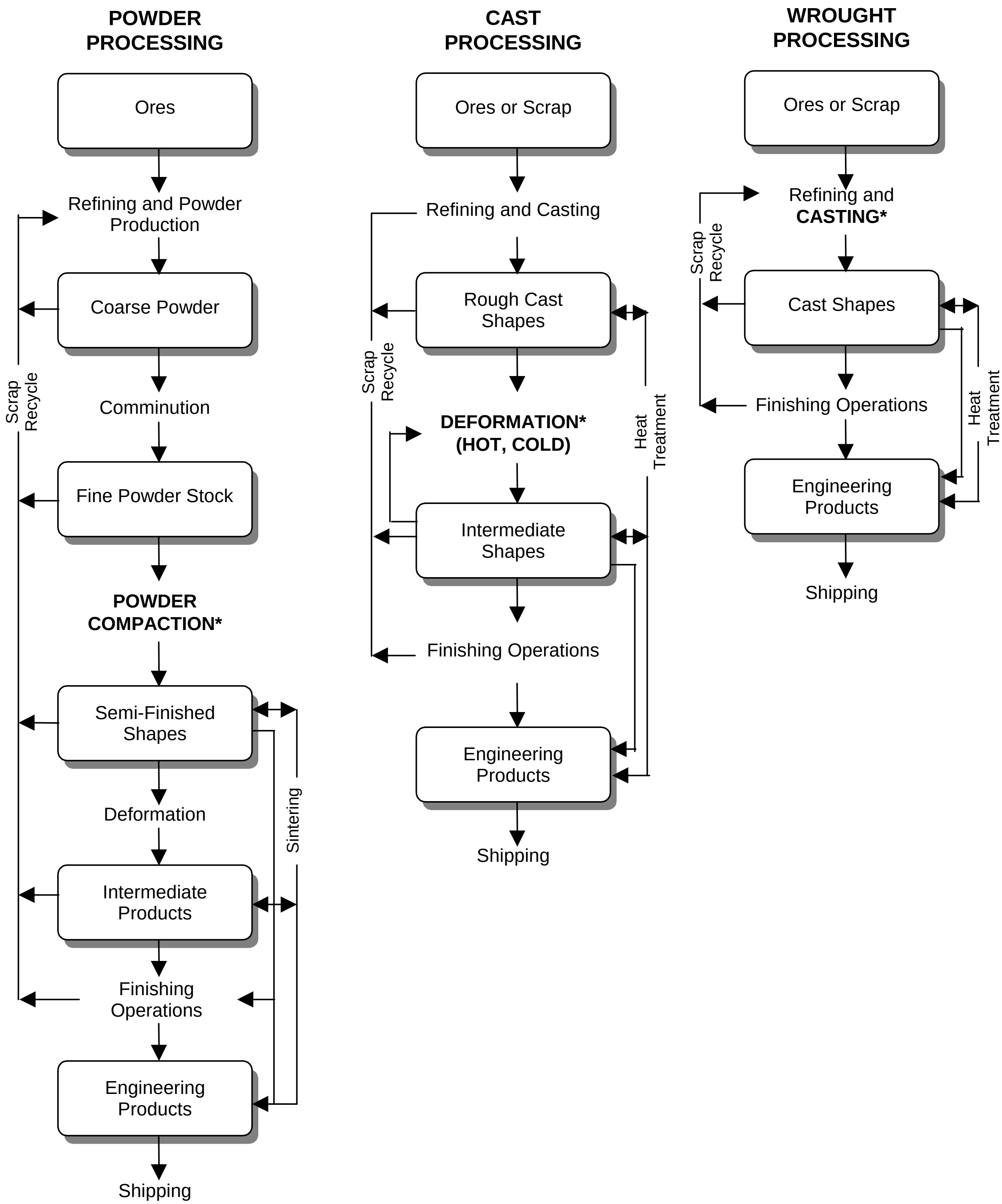
Energy consumption figures were not available specifically for SIC 33991. Table 9 listed below shows DOE electricity consumption statistics for the primary metals industry (SIC 33) in 1994.

Table 9. SIC 33 Major Electricity End-Uses (1994)

End Use	Percent of Total
Electro-Chemical Processes	**37.9%**
Machine Drive	**27.4%**
Process Heating	**25.3%**
HVAC	**3.0%**
Facility Lighting	**3.0%**
Facility Support, Other	**2.4%**

Source: DOE Energy Information Administration

Figure 3. Traditional Concepts Regarding Processing of Metallic Products

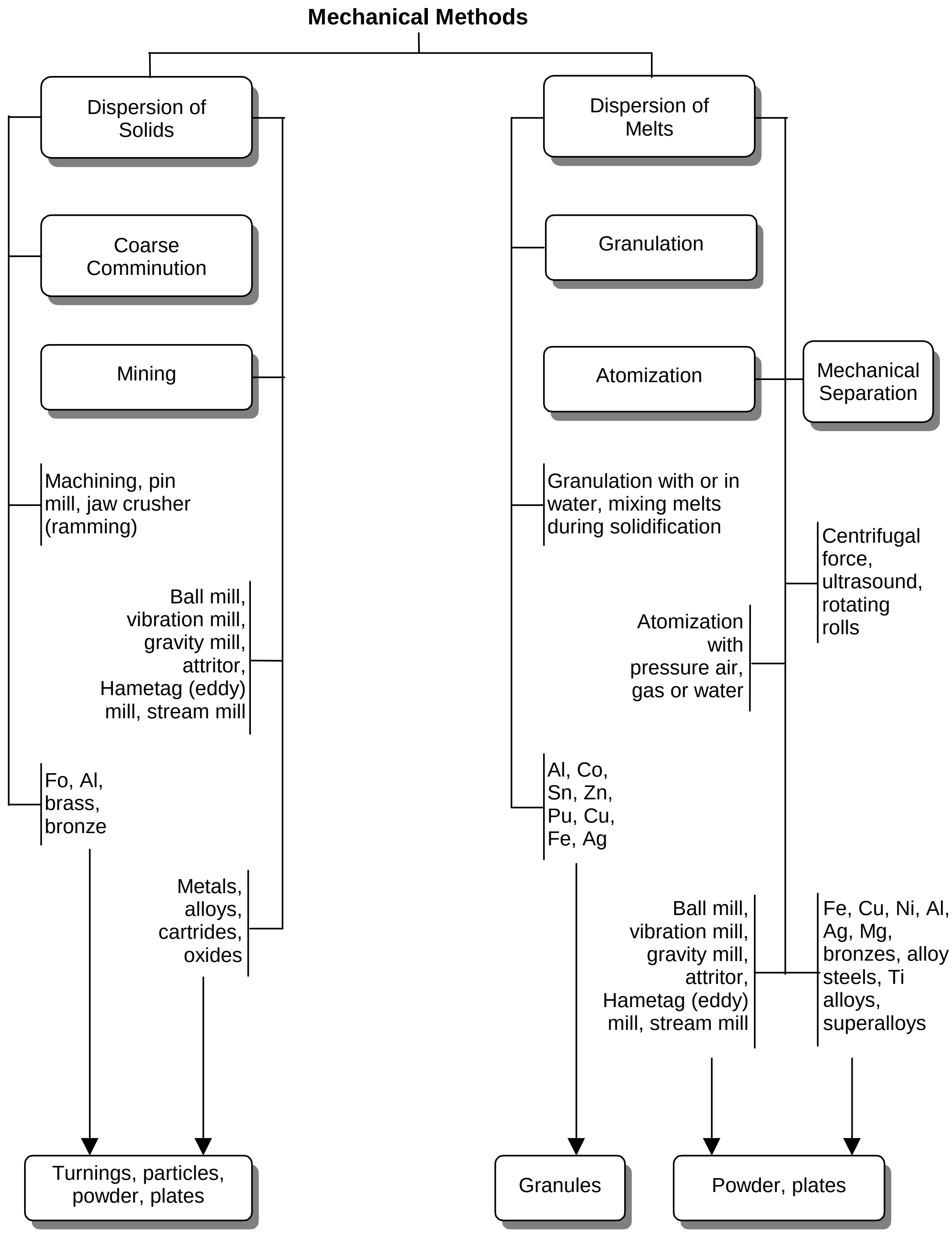


Manufacturing Process Issues

Metal powder production techniques (Figures 4 and 5) are used to manufacture a wide spectrum of metal powders designed to meet the requirements of a large variety of applications. Powders of almost all metals can be produced. Various powder production processes allow precise control of the chemical and physical characteristics of powders and permit the development of specific attributes for the desired applications. Powder production processes are constantly being improved to meet the quality, cost and performance requirements of all types of applications.

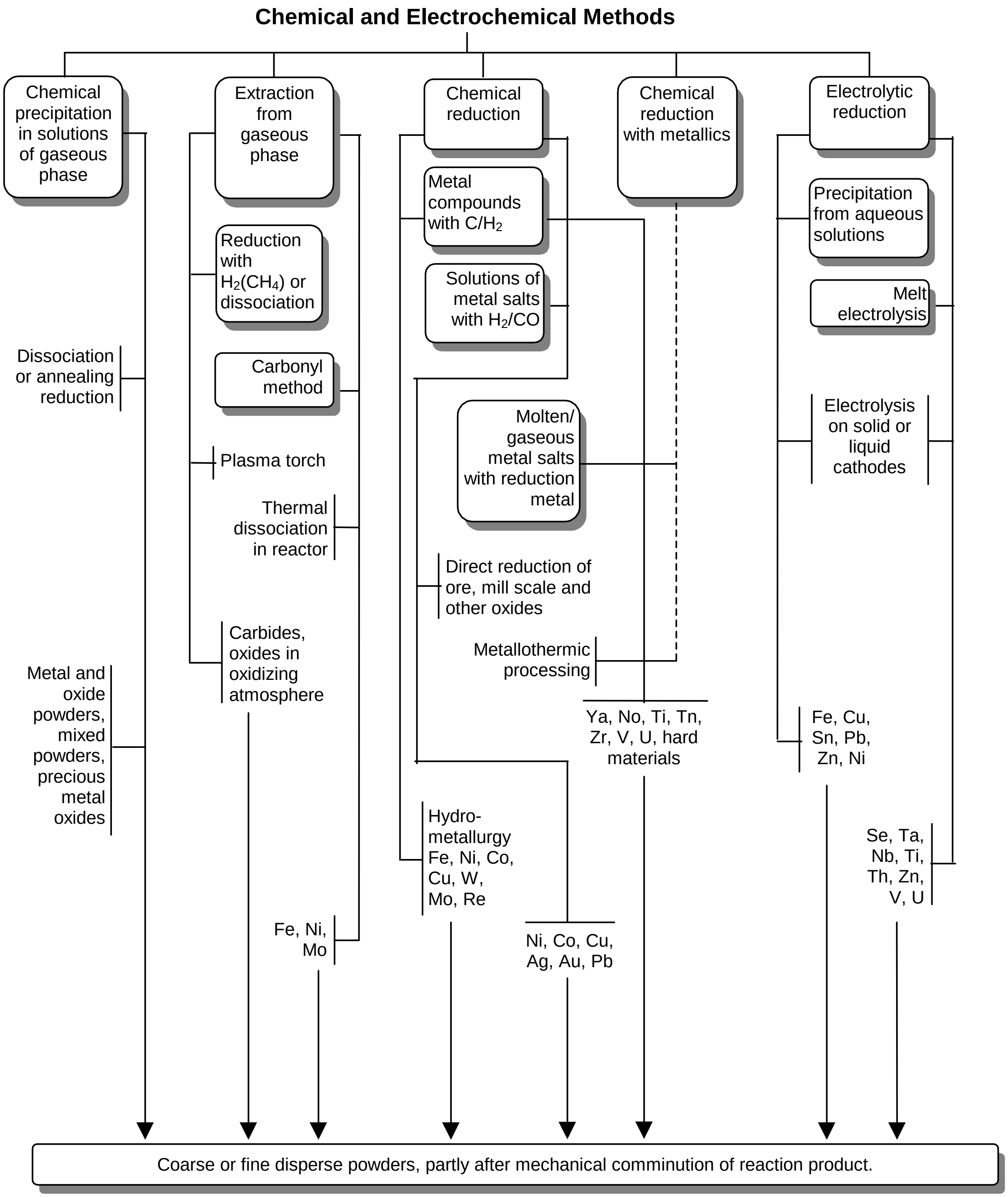
- Metal powders are produced by mechanical or chemical methods. The most commonly used methods include water and gas atomization, milling, mechanical alloying, electrolysis, and chemical reduction of oxides.
- Which powder production process is used depends on the required production rate, the desired powder properties and the properties desired in the final part. Chemical and electrolyic methods are used to produce high purity powders. Mechanical milling is widely used for the production of hard metals and oxides.
- Atomization is the most versatile method for producing metal powders. It is the dominant method for producing metal and pre-alloyed powders from aluminum, brass, iron, low-alloy steel, stainless steel, tool steel, superalloy, titanium alloy and other alloys. The various atomization processes are shown in Figure 6.
- For the production of ultra fine or nano-powders, a growing market, gas phase reactions, spray drying or precipitation methods are used.
- Powder metal can be produced in the form of sponge or atomized powders.
- In the case of iron, sponge powder is produced from magnetite iron ore that is directly reduced at elevated temperatures to obtain sponge form. The material is then disintegrated into powder and annealed to obtain the desired properties.
  - Sponge iron has a very high surface area and exhibits high green strength.
  - It is used for low and medium density ferrous P/M parts.
- To produce atomized powders, molten steel is atomized into irregular and homogeneous particles that are then annealed. The melt stock and the subsequent processing are carefully controlled to produce uniform steel powders designed for higher density P/M parts.

Figure 4. Mechanical Methods of Powder Production



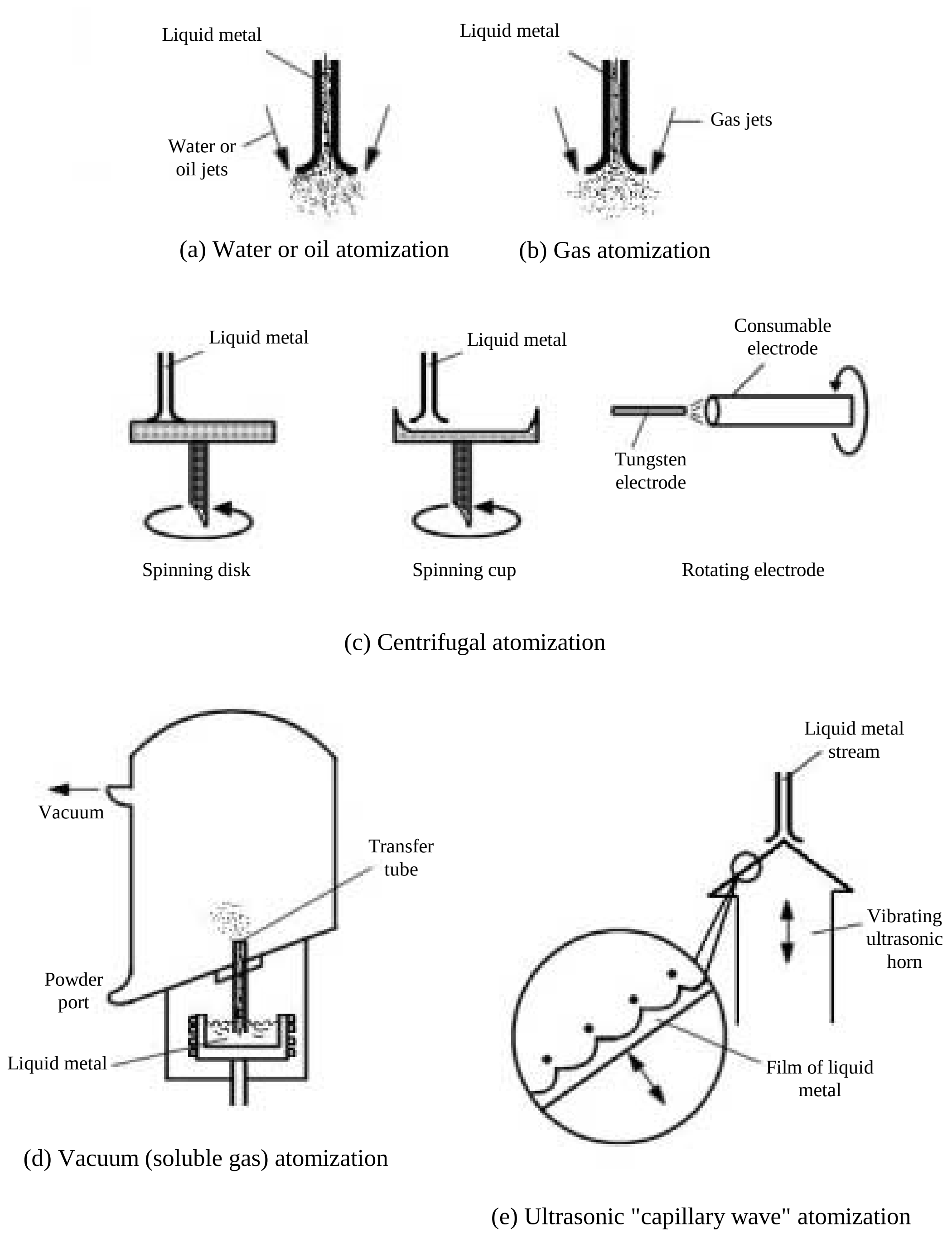
000000000001000133

Figure 5. Chemical and Electrochemical Methods of Powder Production



000000000001000133

Figure 6. Atomization Processes



Technology Trends

Technology advances in the production area are concentrated on improving throughput of process equipment to lower costs, designing process equipment so less maintenance is required, and modifying the equipment to produce powder with more consistent quality and properties. Installation of computerized process controls is part of most upgrades. Significant effort is being applied to accurately model the processes for producing metal powders. For example, gas atomization processes are being improved through advances in computational fluid dynamics modeling.

Technology advances in manufacturing processes are directed to improved properties and lower cost materials.

- Improvements in hot isostatic pressing (HIPing), P/M forging, metal injection molding (MIM), spray forming, high temperature vacuum sintering, and direct powder rolling are increasing the markets for metal powder.
  - MIM is projected to grow at 20% to 25% annually. Key MIM markets are medical applications and business machines, though automotive applications should increase significantly. Fuel injection, air-bag systems, seat belts, small gear-box parts, and transmissions are potential MIM applications
  - Development of ferrous powders with machinability-enhancing manganese sulfide inclusions.

Research in sinter hardening and materials characterization has led to optimized powder formulations to meet high performance requirements. The goal has been not only to maximize performance, but also to match the specific cooling rates of available sintering furnaces.

Advances in high-nitrogen HIP P/M processing have led to improved corrosion resistance in austenitic stainless steels.

The availability of titanium and titanium alloy powders has contributed to increases in production capability of gamma titanium aluminide and other advanced titanium alloys that are difficult to cast using conventional methods.

The use of P/M hot forged connecting rods in automobiles and a P/M camshaft for 4 and 8 cylinder automobile engines. The use of P/M composite camshafts in auto engines and main bearing caps, ABS sensor rings and exhaust system flanges.

- Composite metal camshafts will be designed with powder metal lobes.

New submicron and nanophase powders for cutting tool and other specialized applications.

Special grades of copper, tin and bronze powders for rapid prototyping are being developed to replace lead and for use in artistic applications.

- Bronze powders with improved flow and green strength, improved part ductility, and radial crushing strength have been developed for bearing applications by using a modified water atomization process.

Catalyst applications within the chemical industry have been developed to take advantage of the high available surface area of metal powders, especially particulate.

- Metal powders are being used as catalysts in the negative electrode of rechargeable batteries.
- Nickel powders with a special morphology and cubic shape, in addition to a narrow particle size distribution and large surface area, have also been developed for industrial chemical applications.

Improved annealable composite powders for magnetic applications raise permeability, flux capacity and lower hysteresis losses

Major methods for making metal powders are atomization of molten metal, reduction of oxides, electrolysis and chemical reduction.

There are significant differences between powder metal production and conventional processing of metal.

- Powder production is 25% less energy intensive than conventional metal processing techniques, when scrap loss and deformation costs are considered.
  - Cost savings are realized with single step, near net shape forming. Higher material utilization (97%), and lower energy costs for secondary operations (such as machining) account for significant downstream energy savings, compared to conventional cast or wrought metal processing.

Aluminum based powdered metals are finding increasing use in automotive applications:

- Alloying additions can be incorporated at higher levels than possible with conventional press-and-sinter technology
  - Rapid solidification enables higher solubility for elements such as silicon, iron, chromium, manganese, and nickel.

Environmental Regulations and Issues

In 1997, the primary metals sector (SIC 33) reported Toxic Release Inventory (TRI) emissions of 694.7 million pounds of emissions or 27% of all TRI emissions reported for 1997. Only the chemicals manufacturing industry, with TRI emissions of 797.5 million pounds, reported a higher number.

- The metal powder segment is only a small percentage of the primary metals sector (<0.5% tonnage-wise) and did not have any company listed in the top 25 TRI emitters according to the EPA. However, some of the same technologies used for melting and refining metals within the powder metals sector are the same types of technologies used in the primary metals sector.
  - The principal melting technique within the powder metals sector is the electric arc furnace. The same EPA regulations and restrictions apply to powder metals producers, though on a significantly smaller scale. The powder metals industry must abide by these regulations.
  - TRI data is not available for the specific metal powders industry.

Metals subject to the most stringent EPA regulations include:

- Chromium, beryllium, nickel and other alloys that have already been established as carcinogenic substances in the form of the actual alloy or salt derivative.
  - Nickel salts have been established as carcinogenic, though finished nickel powders have not yet been established as carcinogenic.
- Aluminum powder due to its high explosive potential in ultra fine powder form.
  - An explosion in the early 1990's occurring during the loading of a truck shipment of aluminum powder drew considerable attention from both the EPA and OSHA.
- Carbonyl iron, carbonyl nickel and other alloys produced by the carbonyl process.
  - The fine powders produced by the carbonyl process pose a respirable risk if not handled properly.

Specific on-site releases for the 1997 TRI data for the primary metals sector (SIC 33) include:

- 33.4 million pounds of fugitive or nonpoint air emissions (10.5% of TRI total)
- 98.7 million pounds of stack or point emissions (9.7% of TRI total)
- 48.0 million pounds of surface water discharges (22.0% of TRI total)
- 846 thousand pounds of Class 1 injection to underground wells (0.4% of TRI total)
- 14.0 million pounds of RCRA on-site land releases to (68.3% of TRI total)
- 55.2 million pounds of other land releases (59.0% of TRI total)

The most significant off-site releases for the 1997 TRI data for the primary metals sector (SIC 33) were:

- 120.3 million pounds of solidification/ stabilization metals (83.3% of TRI total)

Opportunities for Increased Electricity Use

Major electrotechnology applications in the metal powder industries include

- Melting and refining of metals:
  - Larger powder producers typically use electric arc furnaces to melt iron and steel.
  - Metal melting of amorphous powders and other specialty alloys includes many opportunities for induction melting.
  - Direct synthesis technologies (e.g., plasmachemical synthesis or self-propagating high temperature synthesis that simultaneously form the desired composition and product (in form of powder or dense compact).
- Powder compaction equipment:
  - Combined compaction and sintering by passing electrical-derived energy directly into the powder masses.
- Heating for powder treatment or sintering:
  - Heat treatment of metal powders by induction.
  - Replacing fossil fuel direct combustion heating with electrotechnologies.
- Electric motors and vacuum pumps for increased use of vacuum processing of powder metals.
- Improved process control and increased automation of powder production through advances in computer controlled process technology.

Areas of Decreased Electricity Use

- Increased lighting efficiencies.
- Increased motor efficiencies.
- Decreased electricity use in EAFs through increased use of oxygen.

Opportunities for Electric Utilities

The primary metal melting technology used by the metal powder producers is the electric arc furnace. Electricity represents proportionately higher costs for the metal powder producer and is a potential opportunity for co-generation.

- The electric utility can pursue a strategy of partnering with the metal powder producer to share some of the risks and rewards of delivering a guaranteed source of power.
  - Power quality issues are significant for industrial customers using EAF technology, and must be worked on jointly between the utility and the customer.
  - Long term contracts can be negotiated with sound communication policies that minimize unforeseen power interruptions or power quality issues.
- The electric utility can pursue a strategy of offering the metal powder producer a rate discount, if they agree to curtailment during peak periods.
  - The metal powder producer is a significant user of electricity, and can have an impact on a utility curtailment program.
  - The metal powder producer may be flexible in rescheduling production, if given sufficient advance notice by the electric utility.

Induction melting systems to enhance melt purity and to reduce environmental emissions.

- Producers considering capacity additions to target the high growth stainless steel automotive applications may be looking at smaller furnaces well suited to induction.

Installation of plasma arc rotating electrode process or tungsten tip rotating electrode process for producing high purity metal powders.

Industry Associations and Periodicals

The following trade associations are resources for industry information and possible collaborative efforts.

Metal Powder Industries Federation
105 College Road East
Princeton, NJ 08540-6692
Phone: (609) 452-7700
Fax: (609) 987-8523
www.mpif.org

American Powder Metal Institute
105 College Road East
Princeton, NJ 08540-6692
Phone: (609) 452-7700
Fax: (609) 987-8523
www.mpif.org

ASM International
Materials Park, OH 44073-0002
Phone: (440) 338-5151
Fax: (440) 338-4634
www.asm-intl.org

US Census Bureau
4700 Silver Hill Rd
Suitland, MD 20746
Phone: (202) 457-2000
www.census.gov

The following trade publications are resources for industry information.

American Metals Market
Cahners Business Information
350 Hudson Street
New York, NY 10014
Phone: (212) 519-7550
Fax: (212) 519-7520
www.amm.com

International Journal of Powder Metallurgy
105 College Road East
Princeton, NJ 08540-6692
Phone: (609) 452-7700
Fax: (609) 987-8523
www.mpif.org

Advanced Materials and Processes
Materials Park, OH 44073-0002
Phone: (440) 338-5151
Fax: (440) 338-4634
www.asm-intl.org

InfoUSA
5711 S 86 Circle
Omaha, NB 68127
Phone: (402) 592-4593
Fax: (402) 537-6167
www.infousa.com

General Reference

ASM Handbook, Vol. 7, *Powder Metal Technologies and Applications*, ASM International, 1998

For Further Information Contact:

The EPRI Center for Materials Production

1251 Dublin Rd

Columbus, OH 43215

Voice: 614/255-2590

Fax: 614/291-2867

cmp@tarateccorp.com

000000000001000133

000000000001000133